MODIS RSB Calibration and Performance

MODIS Characterization Support Team, NASA GSFC
(presented by Kevin Twedt)

Outline

- Review of MODIS RSB specs and on-orbit calibration
- Update on SD degradation, RSB gain and SNR trends
- Collection 7 algorithm improvements
  - Presented at MSWG meeting on December 2, 2020
  - Memos summarizing C7 changes are available at https://mcst.gsfc.nasa.gov/content/collection-7

RSB Design Specifications

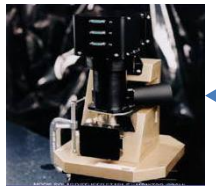
Band	CW*	Ltyp+	SNR	Primary Use
1	0.645	21.8	128	Land/cloud/aerosol boundaries
2	0.858	24.7	201	
3	0.469	35.3	243	Land/cloud/aerosol properties
4	0.555	29.0	228	
5	1.24	5.4	74	
6	1.64	7.3	275	
7	2.13	1.0	110	
8	0.412	44.9	880	Ocean color, phytoplankton & biogeochemistry
9	0.443	41.9	838	
10	0.488	32.1	802	
11	0.531	27.9	754	
12	0.551	21.0	750	
13	0.667	9.5	910	
14	0.678	8.7	1087	
15	0.748	10.2	586	
16	0.869	6.2	516	
17	0.905	10.0	167	Atmospheric water vapor
18	0.936	3.6	57	
19	0.940	15.0	250	
26	1.37	6.0	150	Cirrus cloud water vapor

*μm

+$W/m^2/sr/\mu m$

On-orbit Calibration Activities

SD/SDSM:
Weekly to tri-weekly



Solar Diffuser

SDSM

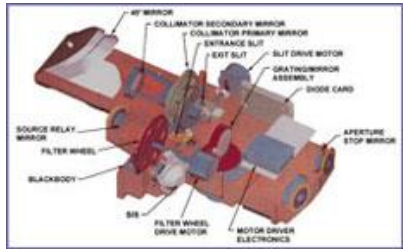
Scan Mirror

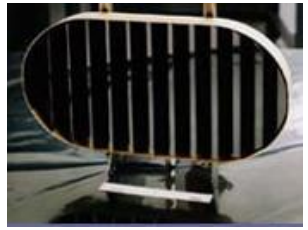
SRCA

Blackbody

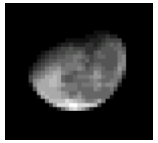
Space View

SRCA:
Radiometric: monthly
Spatial: quarterly
Spectral: tri-annual





BB: quarterly



Moon: monthly (nighttime orbits)
0-20° spacecraft roll maneuvers
55° phase angle

Spacecraft maneuvers:
Yaw (SD BRF, VF)
Roll (Moon)
Pitch (with Moon) for RSB
RVS validation

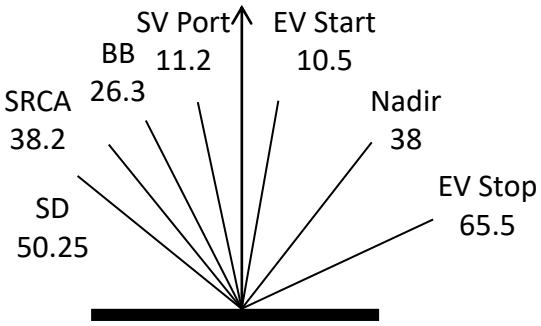
RSB Calibration

- EV Reflectance

$$\rho_{EV} \cdot \cos(\theta_{EV}) = \frac{m_1 \cdot d^2_{Earth\_Sun} \cdot dn_{EV} \cdot (1 + k_{Inst} \cdot \Delta T_{Inst})}{RVS}$$

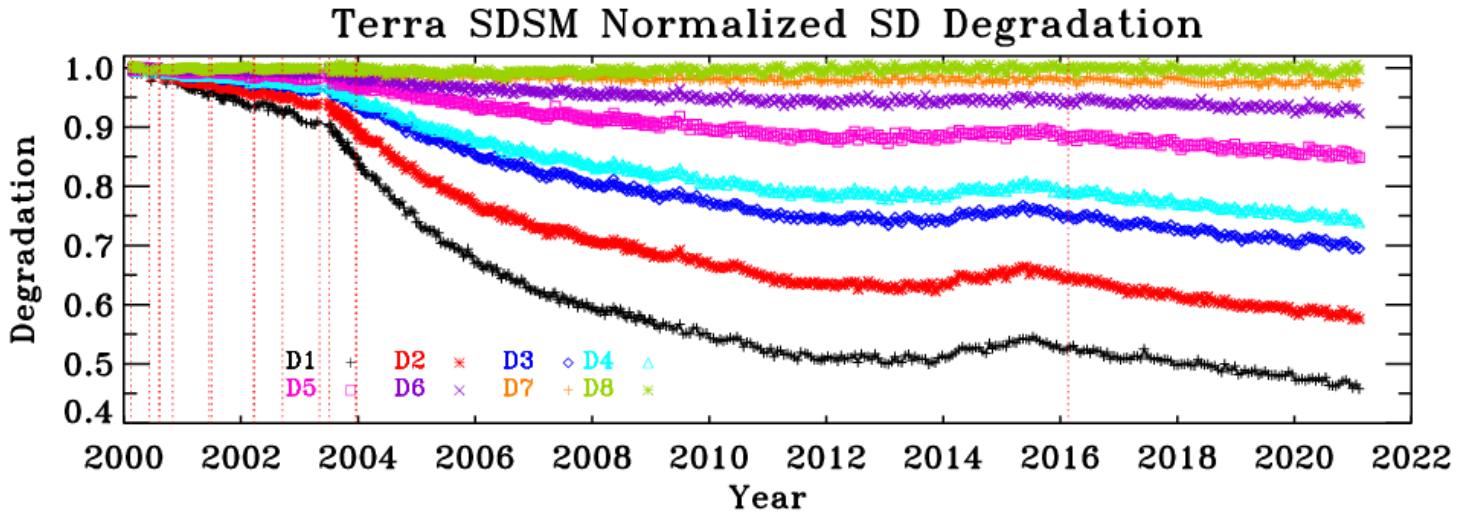
- Look-Up-Tables (LUTs) updated regularly for RSB
  - m_1: Inversely proportion to gain at the AOI of SD
  - RVS : Sensor Response versus Scan angle (normalized to SD AOI)
  - Uncertainty tables

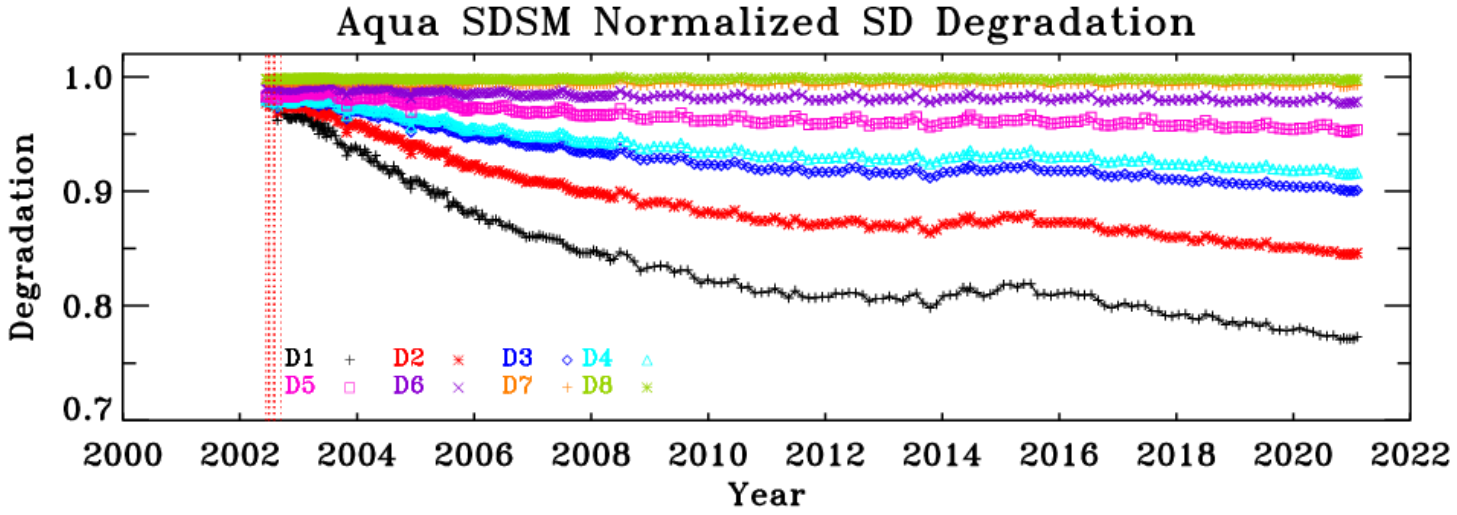
- Calibration Source
  - SD/SDSM calibration
  - Lunar observation
  - EV mirror side (MS) ratios
    - SRCA MS ratios (previously used) are not considered due to lamp failures
  - Response trending from Libya desert targets
    - In C7, EV data from DCC and ocean targets also used



Angle of Incidence (AOI)

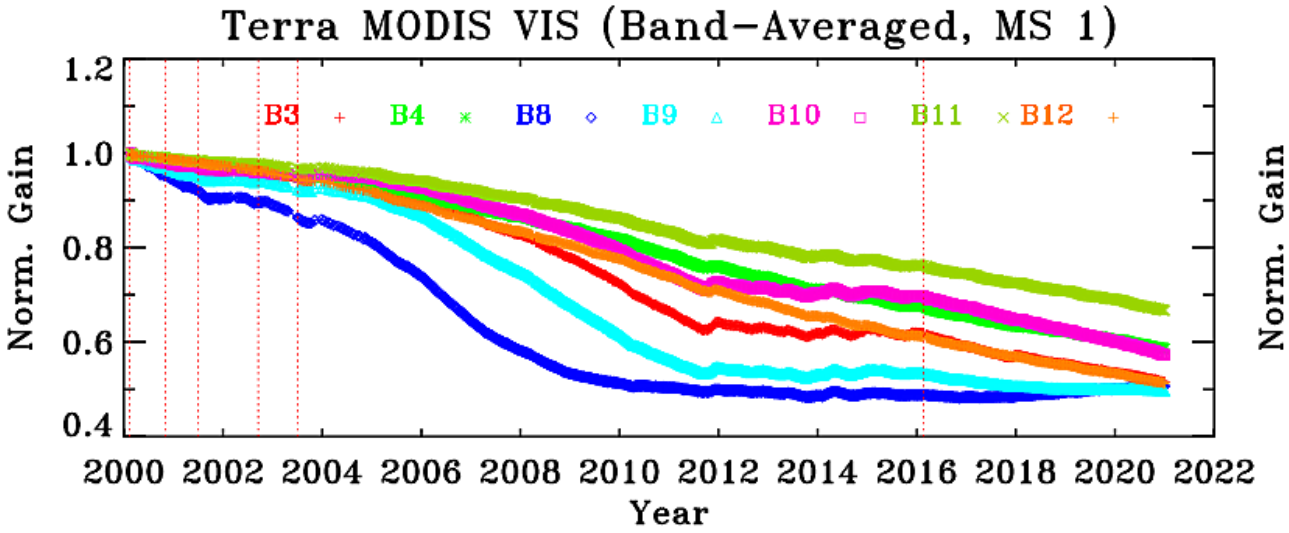
MODIS SD Degradation

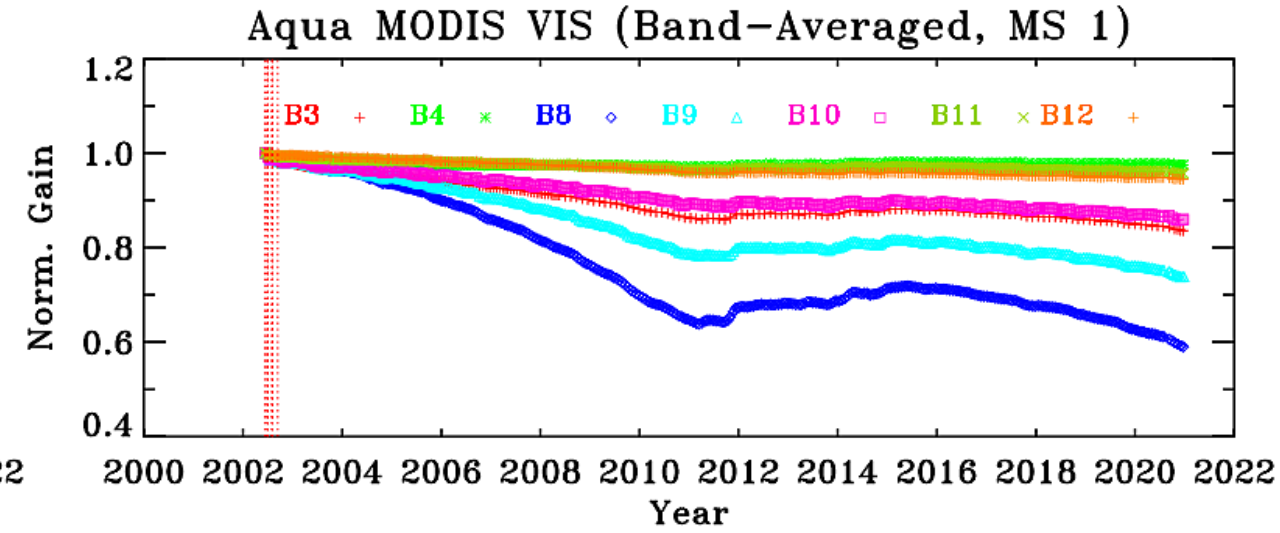




- Increased degradation after Terra SD door anomaly on July 2, 2003.
- Larger SD degradation at shorter wavelengths for both instruments
- A special “fix” mode operation was performed for Aqua MODIS SDSM in October 2020 to verify the results observed in previous years

VIS Gain Trending from SD





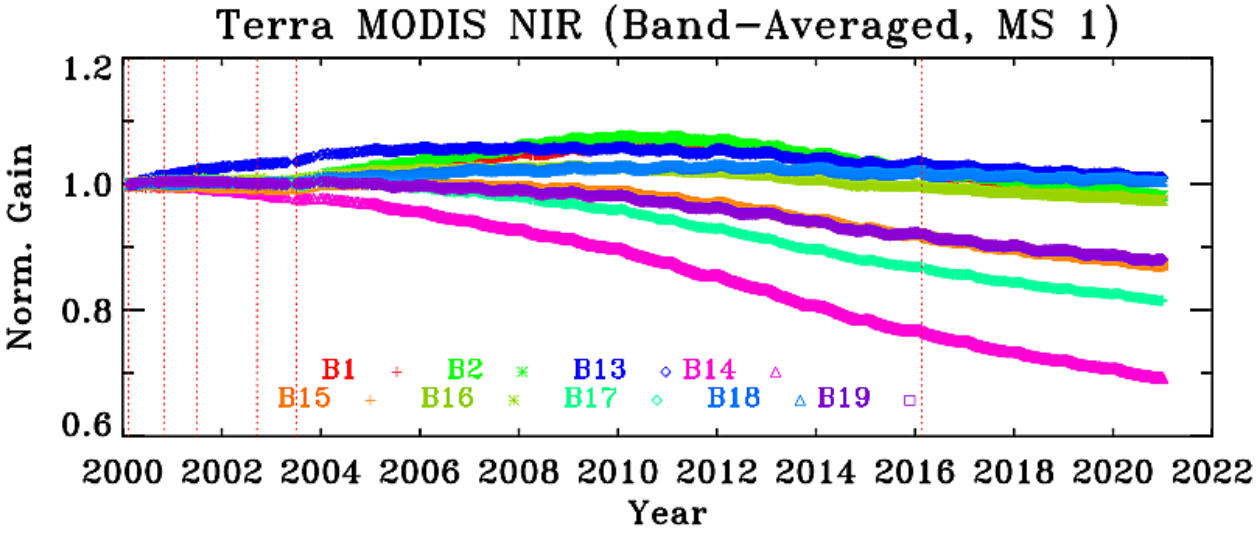
Terra

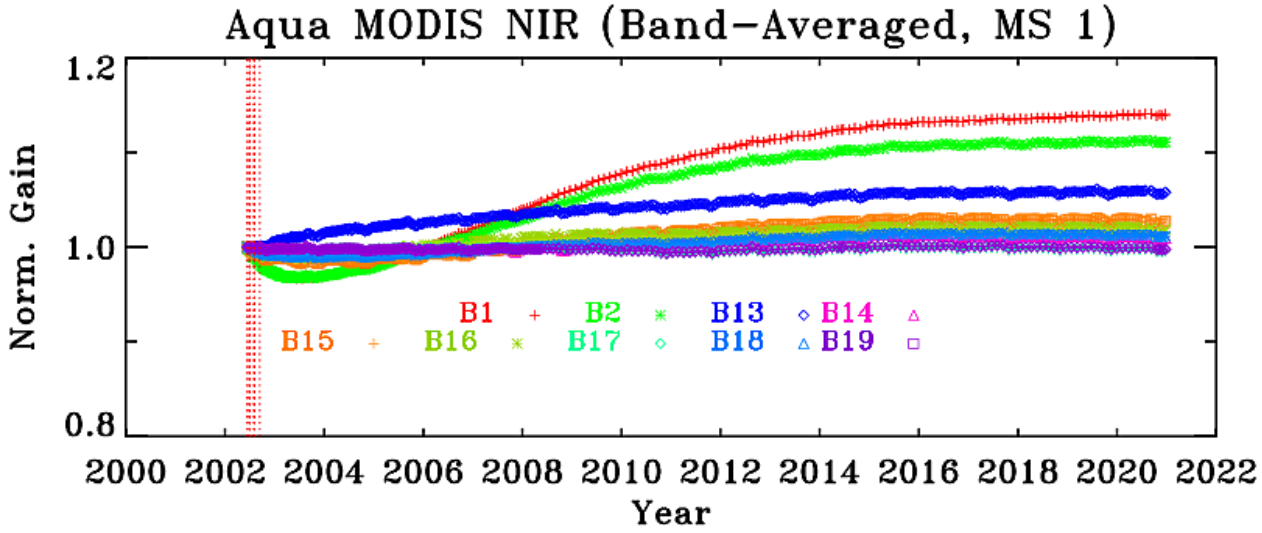
- Most change observed for short-wavelength bands
- Band 8 (.412 µm) changes by over 50%
- Terra VIS bands have a maximum mirror-side difference of about 11% at the SD AOI

Aqua

- Most change observed for short-wavelength bands
- Band 8 (.412 µm) maximum change is ~40%
- Aqua VIS bands have a maximum mirror-side difference of about 3.5% at the SD AOI (Band 8)

NIR Gain Trending from SD





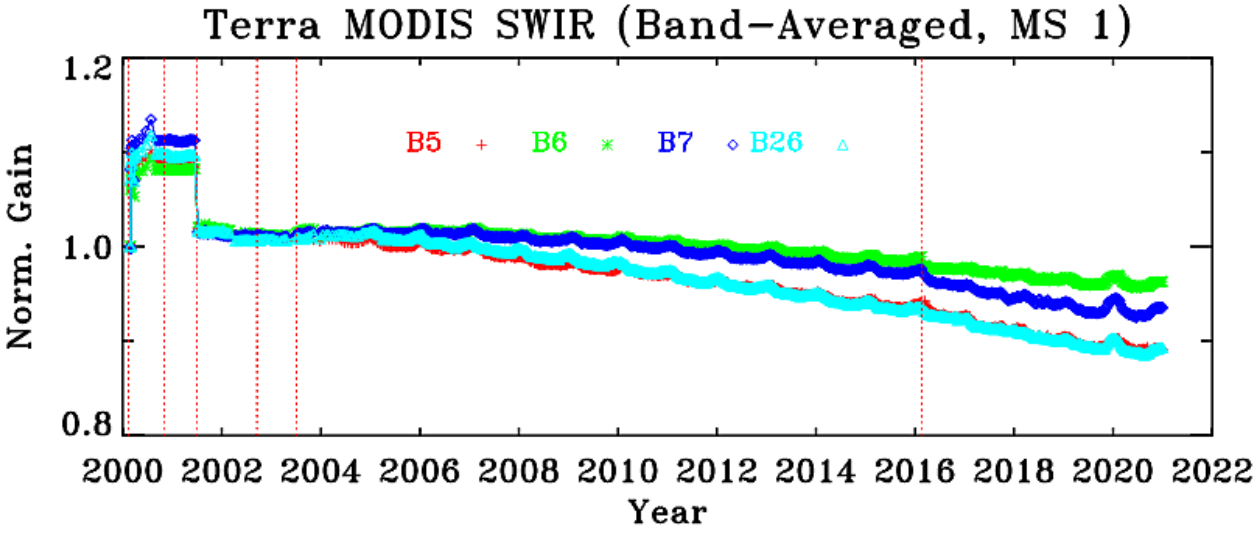
Terra

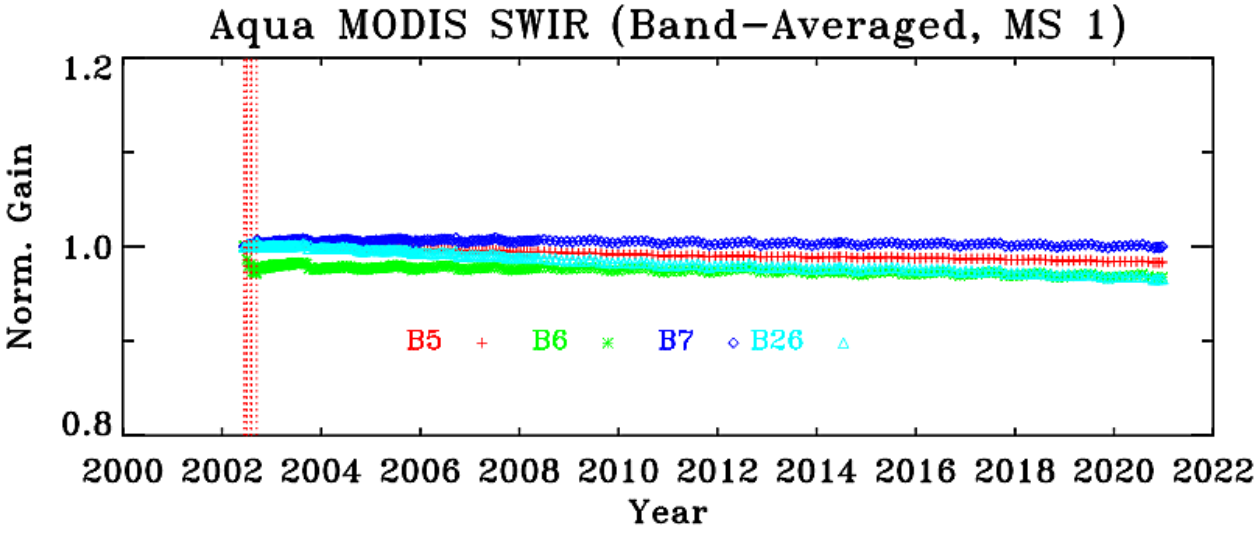
- Changes for most NIR bands are within 15%
- Mirror-side differences are <1%

Aqua

- Changes for most NIR bands are within 6%
- Mirror-side differences are <1%

SWIR Gain Trending from SD





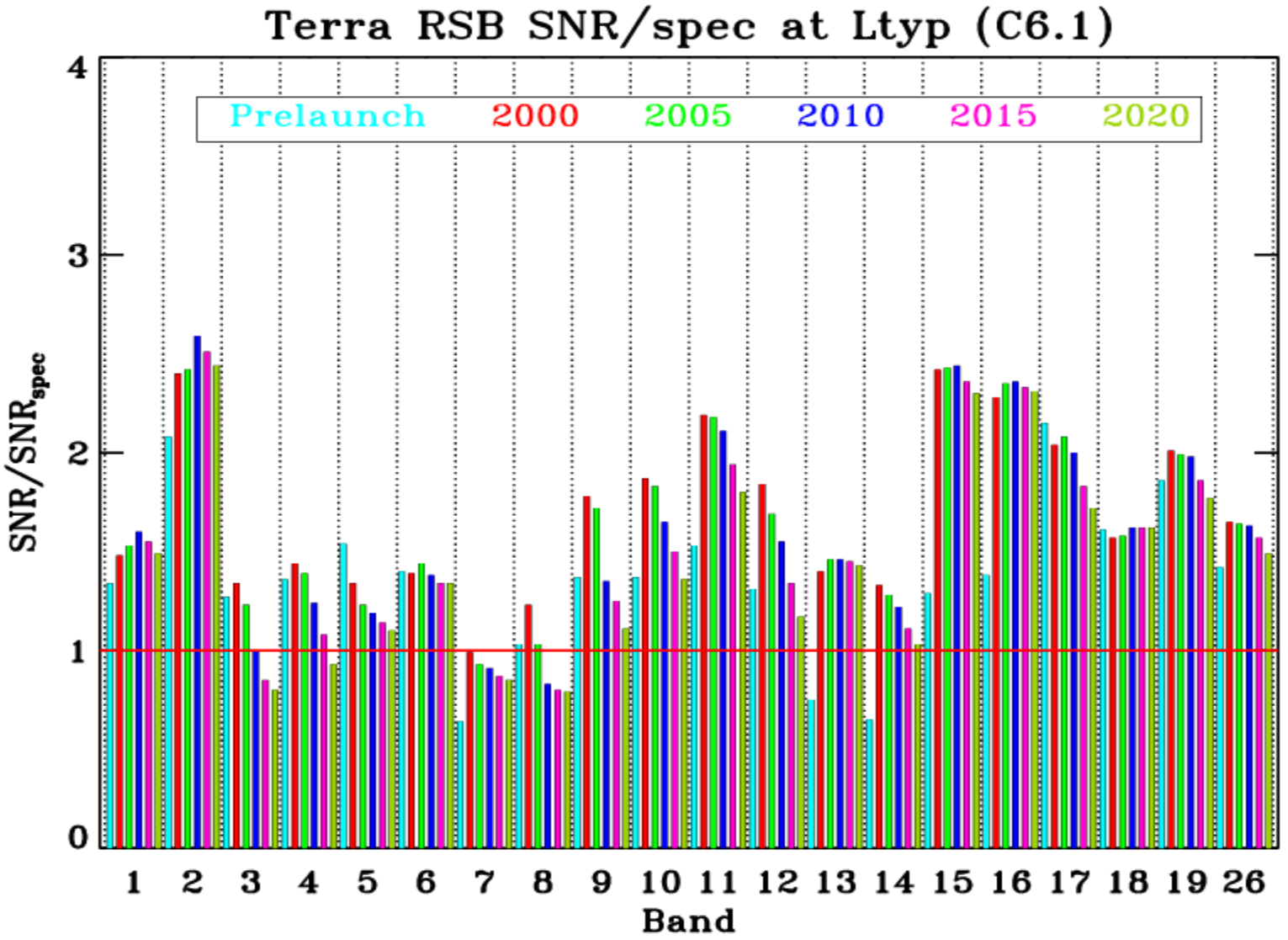
Terra

- All SWIR bands change by < 12%
- Mirror-side differences are <1%
- * Noisy and inoperable detectors excluded

Aqua

- All SWIR bands change by < 3%
- Mirror-side differences are <1%
- * Noisy and inoperable detectors excluded

MODIS RSB SNR Bar-Charts



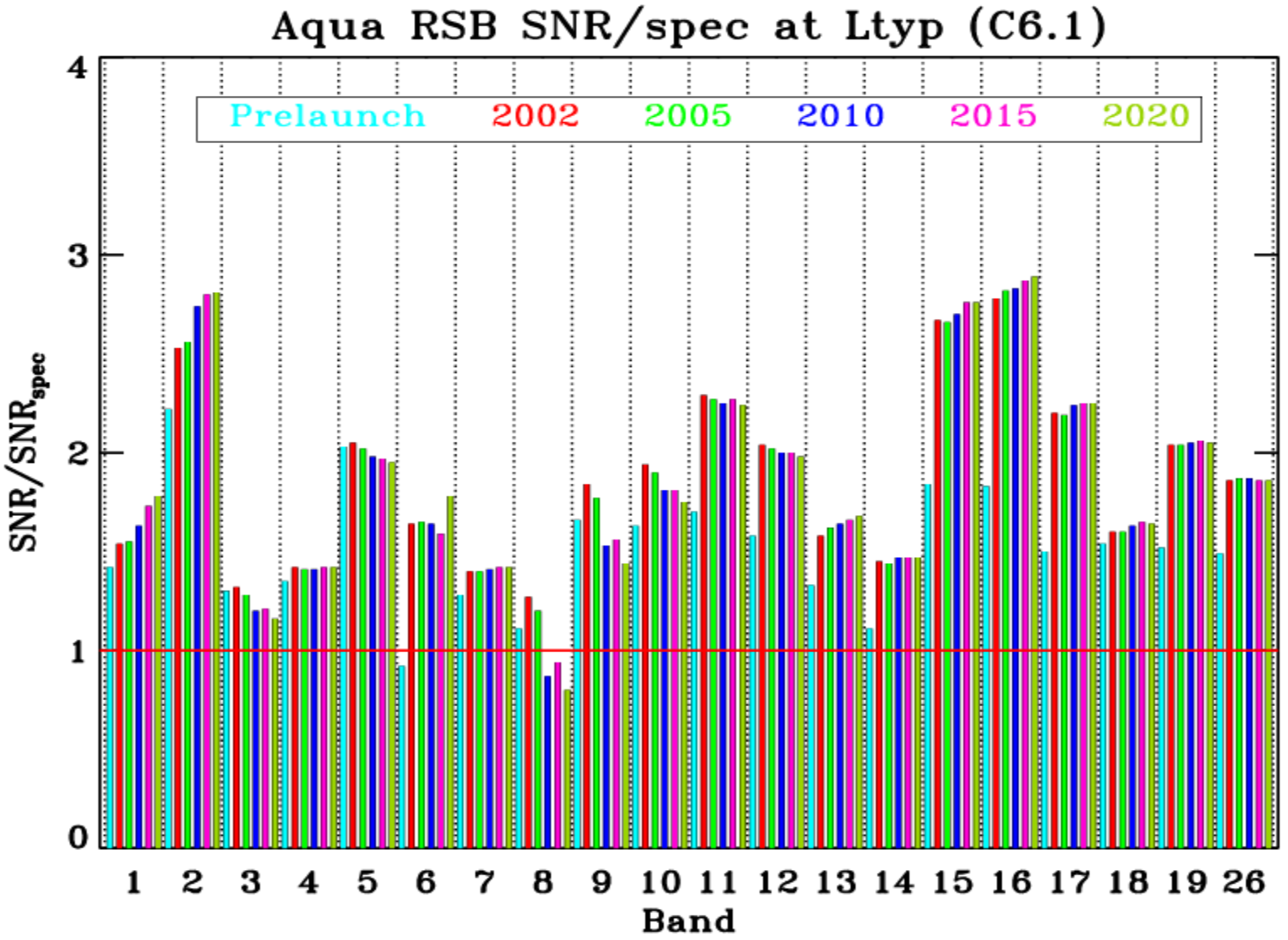
Most bands continue to meet the specification.

- Decreased responsivity for some short wavelength RSB (Terra bands 8, 9, 3, 4)
- Terra band 7 SNR known to be below specification since launch

Since 2019 science team meeting

- No new inoperable detectors
- Two new noisy detectors: band 5 detectors 3 and 5 flagged as noisy starting 2021/035

MODIS RSB SNR Bar-Charts



Most bands continue to meet the specification.

- Decreased responsivity for some short wavelength RSB (Aqua band 8)
- Known issues with the inoperable/noisy detectors in Aqua band 6.

Since 2019 science team meeting

- No new inoperable or noisy detectors

C7 RSB Algorithm Improvements

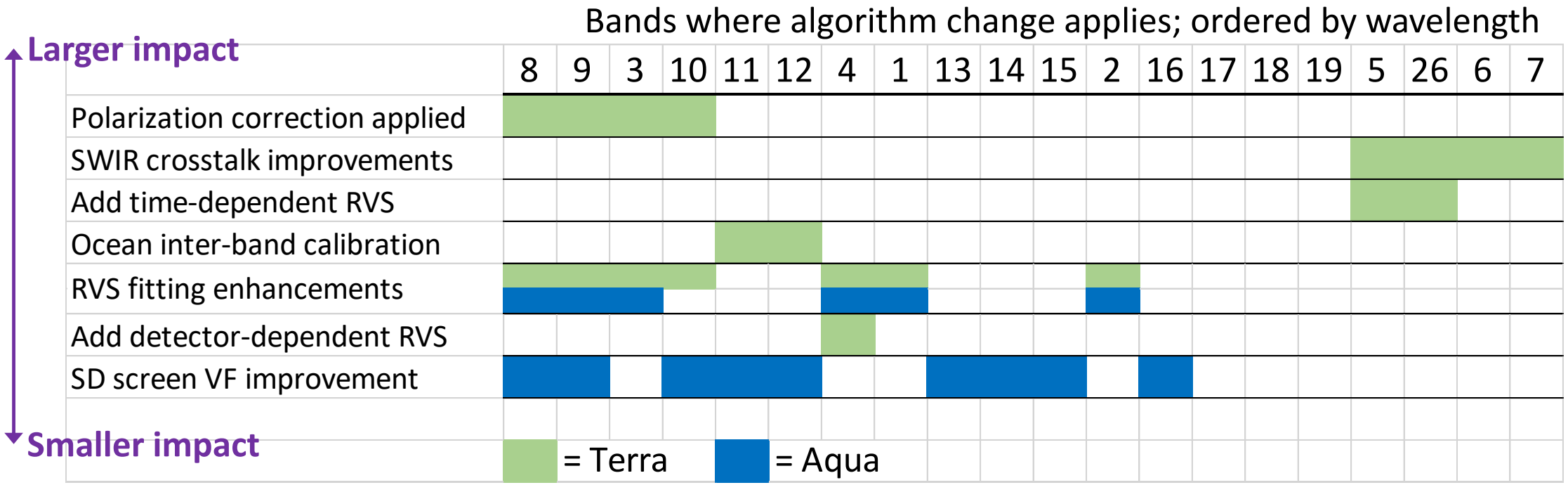
Terra

1) Polarization correction applied to desert data prior to deriving RVS for Terra bands 3, 8, 9, and 10
2) Improvements to OOB/crosstalk correction algorithm for Terra SWIR bands applied for entire mission
   - Implemented in forward Terra C6/C6.1 LUT starting June 2019.
3) SWIR bands 5 and 26 use time-dependent RVS based on DCC data
4) Use an inter-band approach that relies on relative trends of ocean data to derive RVS for Terra bands 11 and 12
5) Improvements to desert data fitting methods for RVS derivation
6) Extend detector-dependent RVS to Terra band 4

Aqua

1) Improved SD screen transmission function applied for ocean bands 8-16
2) Improvements to desert data fitting methods for RVS derivation

C7 RSB Algorithm Improvements



- For all bands, all data inputs have been updated and the entire mission LUTs reprocessed with consistent algorithms to provide more accurate and stable LUTs.

Terra Polarization correction

The polarization sensitivity of scan mirror has impacted performance of Terra MODIS short-wavelength RSB

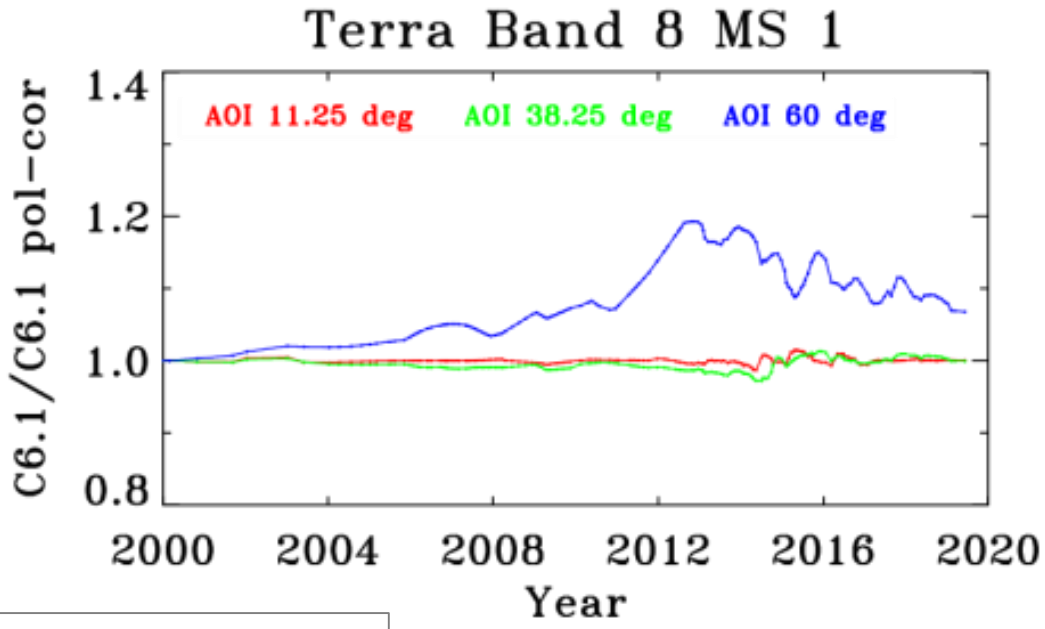
- C6/C6.1 L1B does not include any correction for polarization effects

Current mitigation strategy for L2 products

- NASA OBPG has derived polarization correction coefficients from a cross-cal with SeaWIFS/Aqua MODIS over ocean targets
- For land products, use the OBPG polarization coefficients to generate a L1B_PC product followed by de-trending to correct gain based on desert site trends

Collection 7

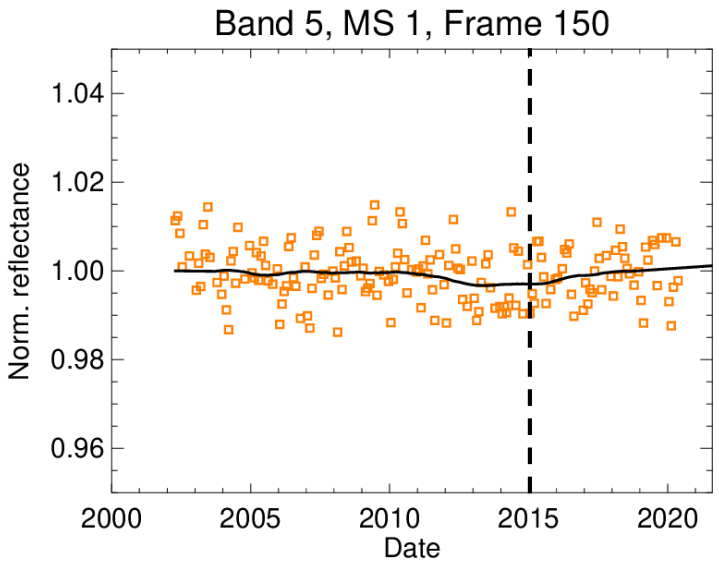
- MCST will apply polarization correction prior to derivation of gain from desert sites for Terra bands 8, 9, 3, and 10.
- **Significant improvement in accuracy of L1B product and forward-predicted gain.**
- **Will significantly reduce the magnitude of downstream gain (M_{11}) and de-trending corrections.**
- **These changes will improve the instrument gain calibration only; there will still be scene-dependent impacts from polarization in the L1B product.**

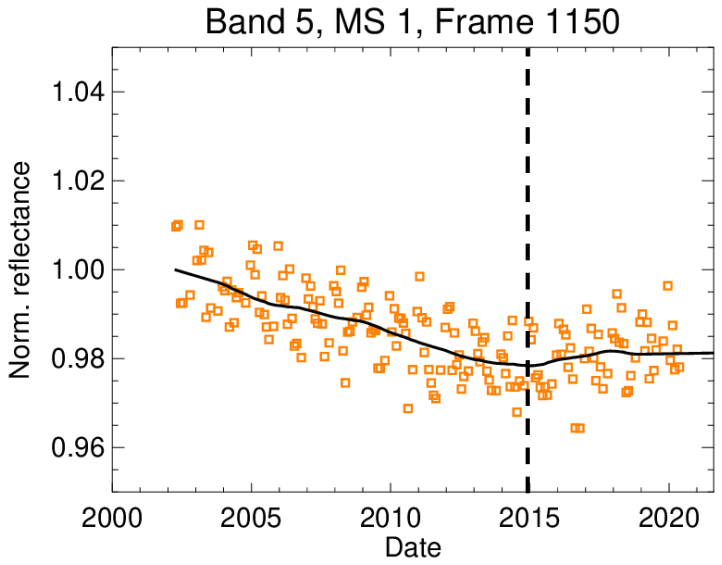


A. Angal et al., IEEE Trans. Geosci. Remote Sensing **58**(8), 5428–5439 (2020)

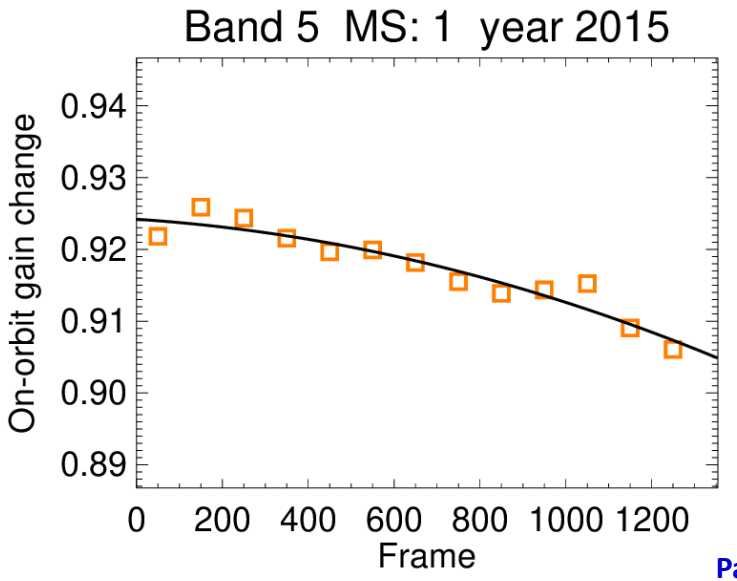
Terra SWIR RVS

- Trends of C6.1 reflectance from DCC and Libya desert sites indicate need for on-orbit RVS*
- Plots show DCC reflectance calculated with only SD-based m_1 and pre-launch RVS.
- Fit in time and frame to derive time-dependent RVS and time-dependent m_1 correction.





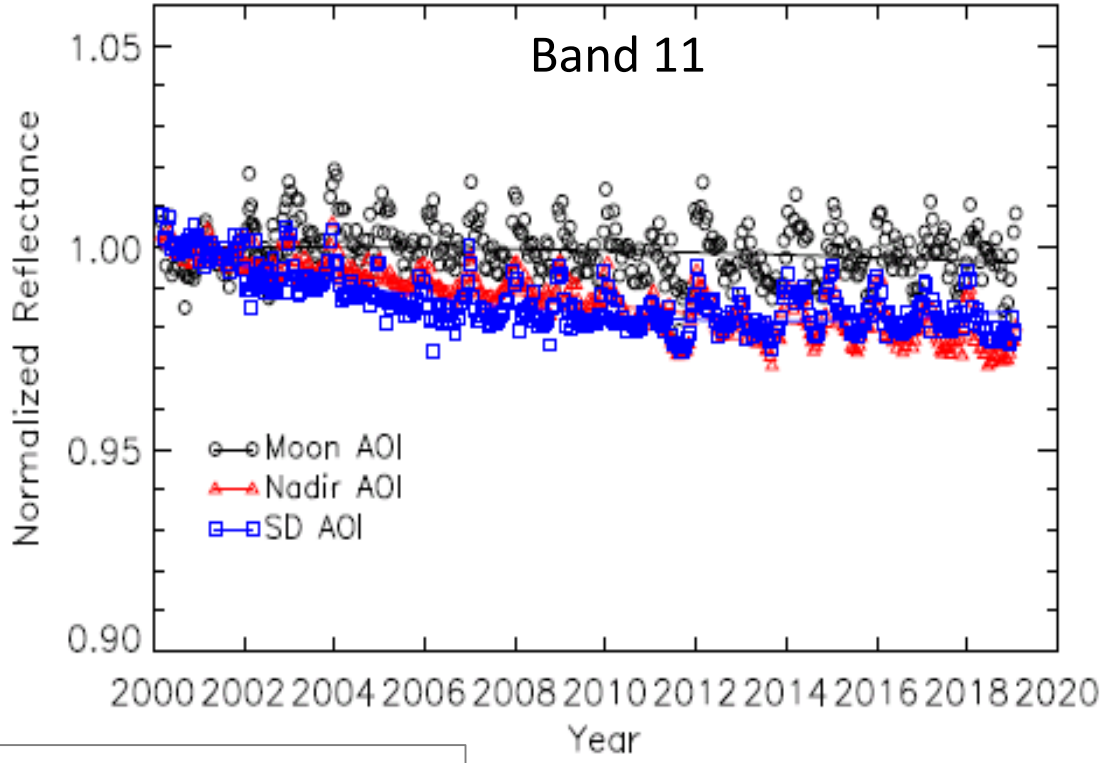
- EV-based RVS applied to band 5 (up to 2% impact) and band 26 (up to 1% impact). Bands 6 and 7 don't show indication of on-orbit RVS change and will continue to use pre-launch RVS.
- EV-based m_1 correction applied to all SWIR bands.
- DCC used to derive m_1/RVS. Results agree with desert data for bands 5, 6, and 7.



*R. Bhatt et al., IEEE TGRS **58(4)**, 2276–2289 (2020)

Ocean interband calibration for Terra B11,B12

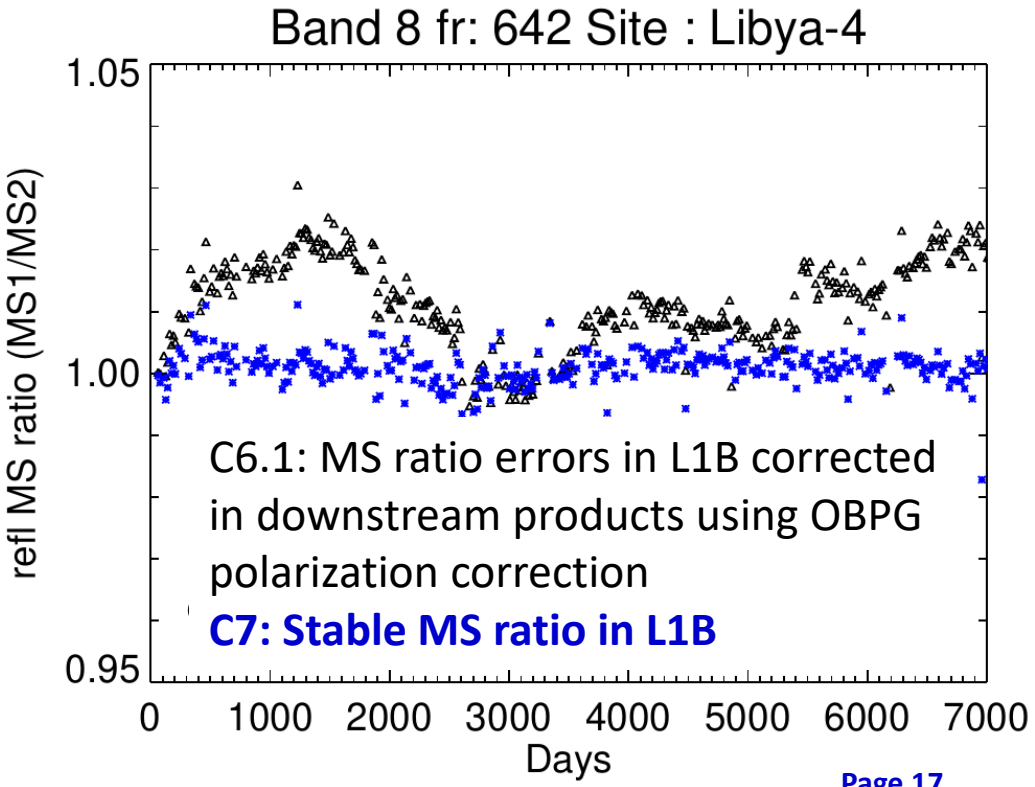
- In C6.1 Terra bands 11 and 12 use only SD and lunar data to characterize m_1 and RVS.
  - Desert trends are used in calibration for other short-wavelength bands 8, 9, 3, 10, and 4.
  - However, the desert-based approach is not viable for bands 11 and 12 (and other high-gain ocean bands) as they saturate while viewing the high-radiance desert.
- An inter-band calibration approach with band 4 (spectrally overlapping) as a reference is used to monitor the long-term reflectance for bands 11 and 12 using ocean scenes.
- Using SD-lunar based calibration, a long-term drift is observed at nadir and SD AOIs for both bands with band 11 showing more than 2% drift, demonstrating the need for EV-based calibration of these bands.
- For C7, these reflectance trends are fit in time and frame to provide adjustment to m_1 and RVS LUTs.



X. Geng, A. Angal, Y. Li, K. Twedt, X. Xiong, Proc. SPIE **11151**, 1115124 (2019)

RVS fitting enhancements

- A few changes/enhancements made to processing and fitting of data from desert observations for RVS derivation (Terra B1-4, 8-10, Aqua B1-4, 8-9)
  1. Use all available view angles from Libya 1, Libya 2, Libya 4 sites (C6/C6.1 used only a select subset of view angles)
  2. Fit over AOI first, then over time
  3. Sliding window averaging (2-year window) to fit reflectance trends in time
- Motivation for making these changes?
  - Fix some minor known problems with fitting of data in C6.1
  - Planning for future de-orbiting period
- Impact of making these fitting changes?
  - **No major change (most <1%) to mission-long band-average trends**
  - Improvement in the reflectance mirror-side ratio for some bands, e.g. Terra band 8

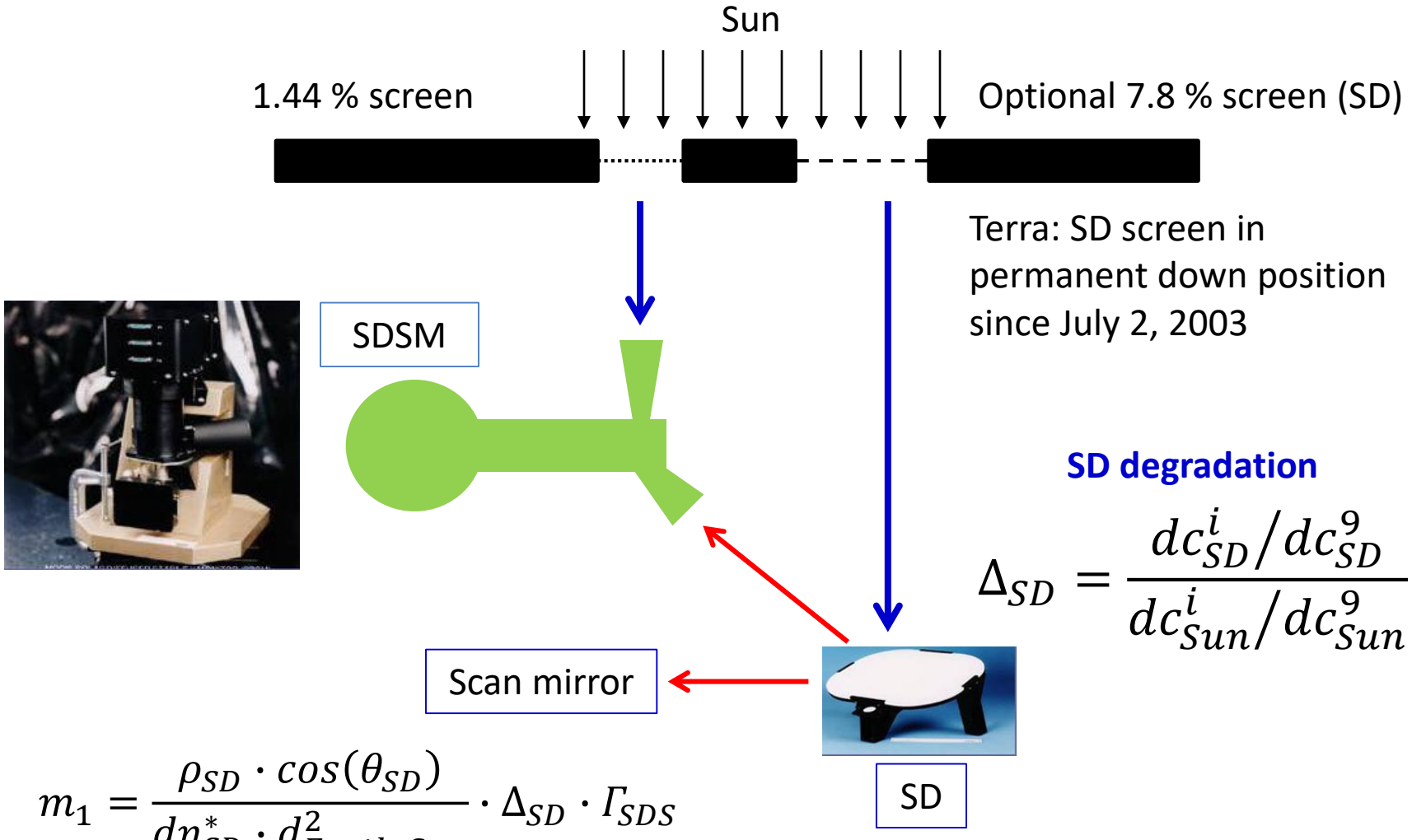


RSB Summary

- SD/SDSM and lunar observations are used to track RSB on-orbit gain change
  - Additional information from EV response from desert sites are used for select RSB (Terra 1-4, 8-10 and Aqua 1-4, 8-9)
- RSB performance is stable. No notable changes in instrument behavior since the last science team meeting (2019).
  - Shorter wavelength VIS Bands show larger degradation (strong wavelength, mirror-side, and scan-angle dependence). Gain change over 50% seen in Terra Band 8 (.412 µm) at the AOI of SD (50.25°)
  - NIR bands gain change mostly within 15%
  - SWIR bands gain change within 10%
- Collection 7
  - Mission LUTs to be delivered in March 2021 and updated going forward
  - Several algorithm improvements included for RSB, mostly impacting Terra MODIS VIS and SWIR bands.
- Future Work
  - Investigations into different calibration strategies to best maintain calibration quality into de-orbiting phase of Terra and Aqua missions

BACKUP

RSB SD Calibration



SD degradation

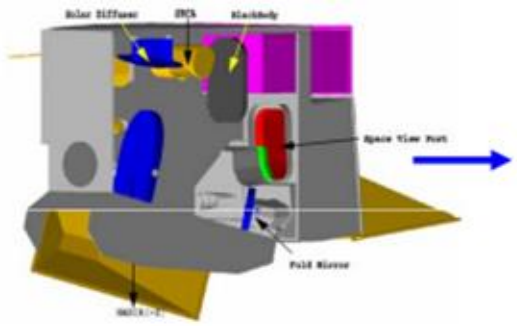
$$\Delta_{SD} = \frac{dc_{SD}^{i}/dc_{SD}^{9}}{dc_{Sun}^{i}/dc_{Sun}^{9}}$$

$$m_1 = \frac{\rho_{SD} \cdot cos(\theta_{SD})}{dn_{SD}^{*} \cdot d_{Earth\_Sun}^{2}} \cdot \Delta_{SD} \cdot \Gamma_{SDS}$$

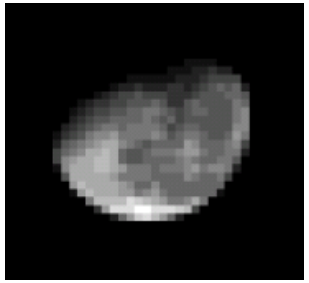
$\rho_{SD} \cdot cos(\theta_{SD}) =$ BRF, dn_{SD}^{*} = Signal from SD (temperature and background corrected), $\Delta_{SD} =$ SD degradation, $\Gamma_{SDS} =$ screen attenuation

RSB Lunar Calibration

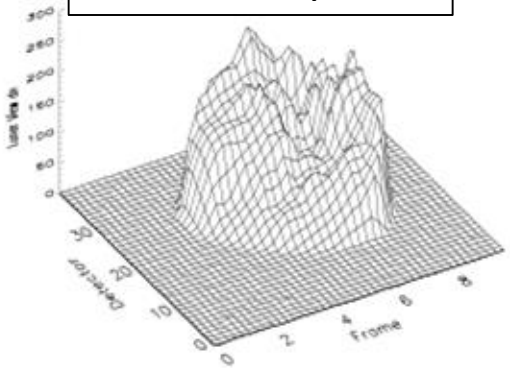
MODIS



Moon



MODIS Response



Near-monthly calibration
Phase angles between 55°- 56°

Lunar calibration coefficients

Bands 1-4, 8-12, 17-19

$$m_1^{moon} = \frac{f_{vg}}{< dn^*_{moon} >}$$

Bands 13-16 (saturated)

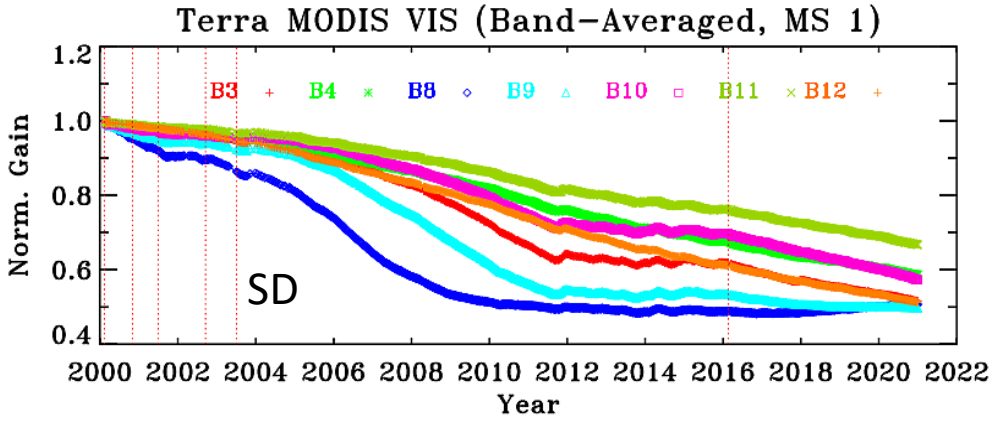
$$m_1^{moon} = m_{1,B18}^{moon} \cdot \frac{< dn^*_{Moon,B18} >}{< dn^*_{Moon} >}$$

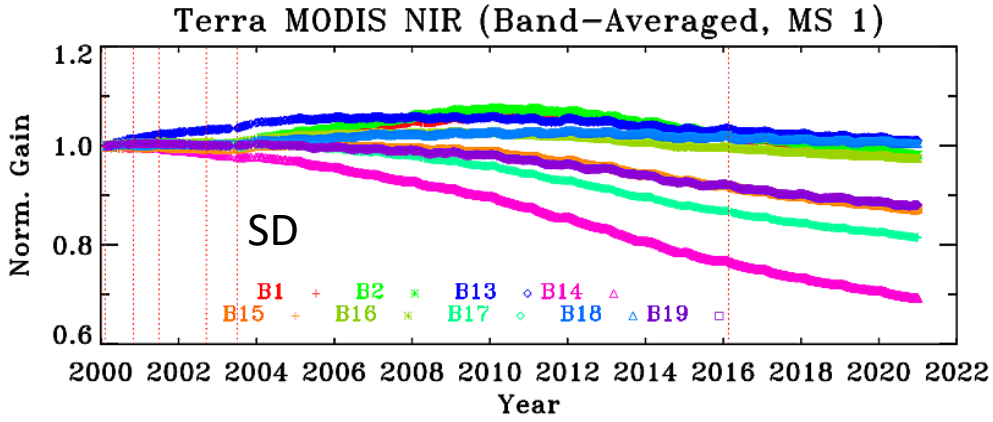
View geometry correction

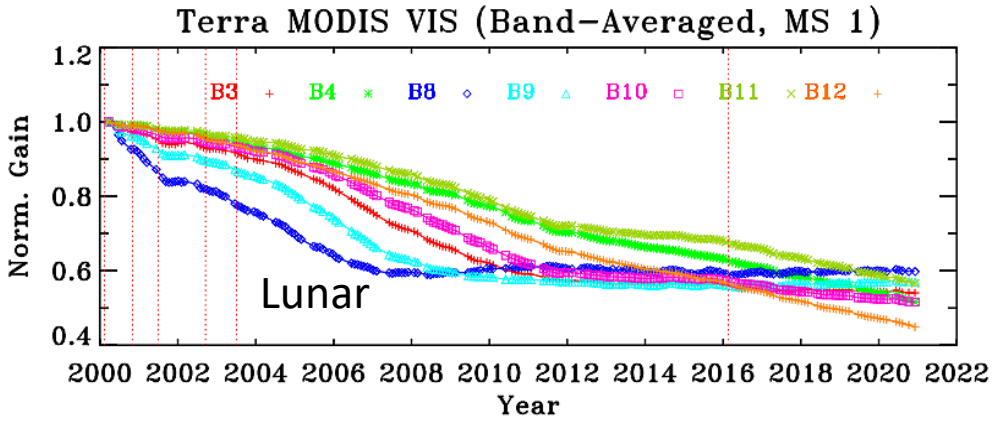
$$f_{vg} = \frac{f_{phase-angle} \cdot f_{libration} \cdot f_{oversampling}}{d^2_{Sun-Moon} \cdot d^2_{Moon-MODIS}}$$

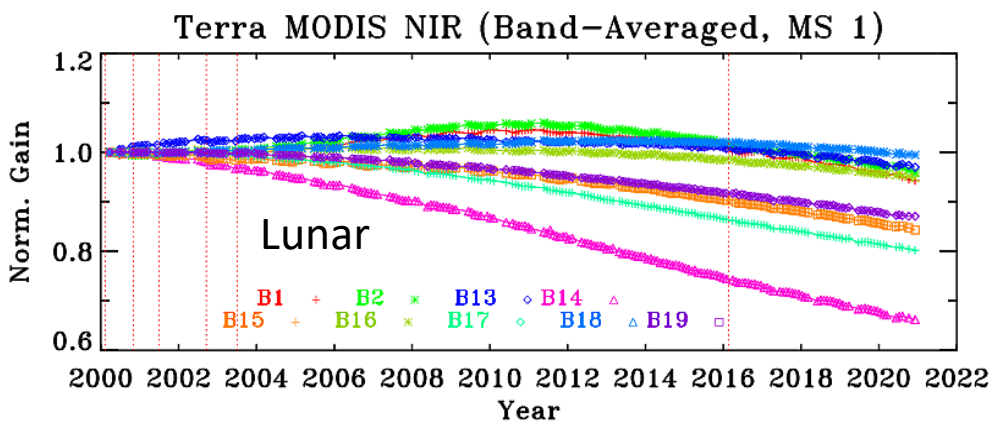
Oversampling effect also needs to be corrected if multiple scans are used

Terra MODIS
Gain Trending from SD and Lunar





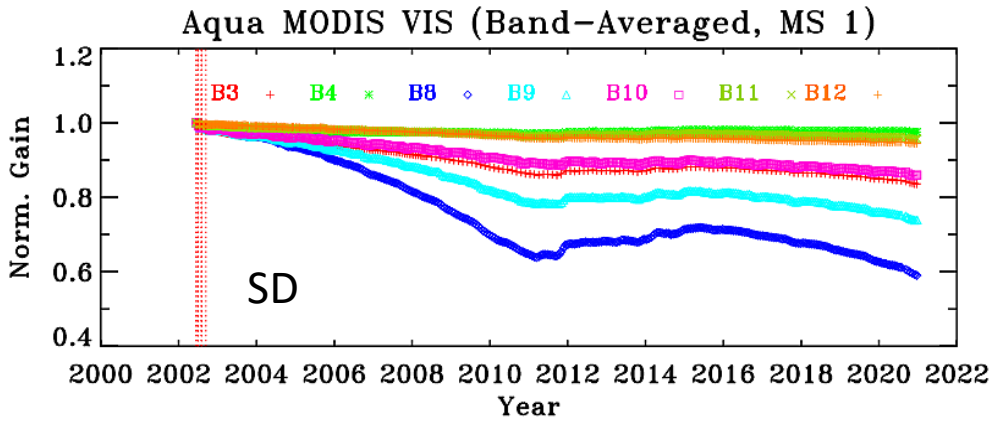


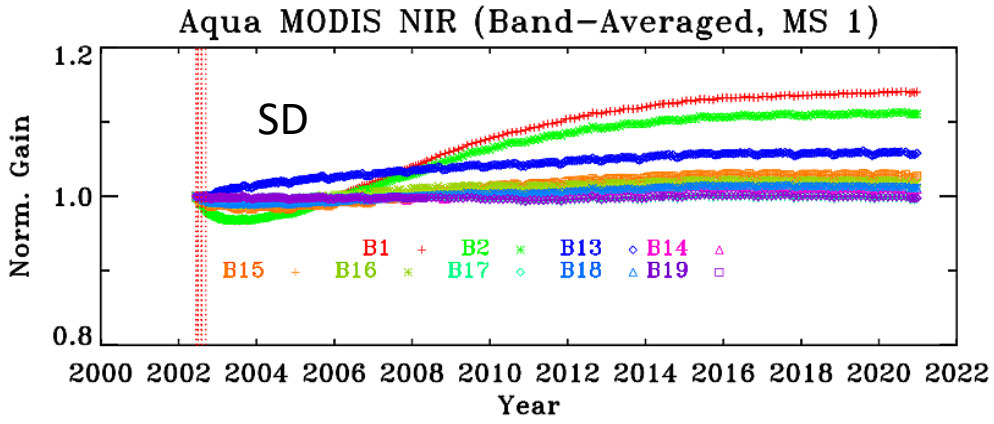


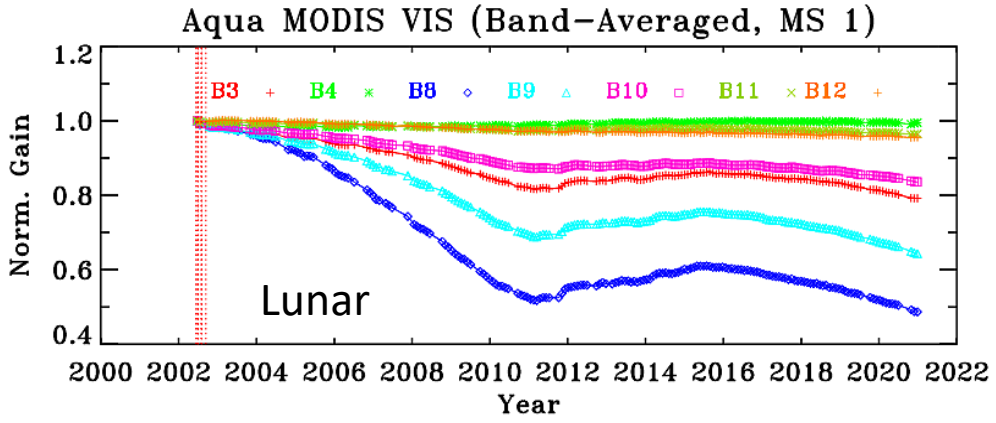
SD & Lunar measurements used to derive the on-orbit RVS change

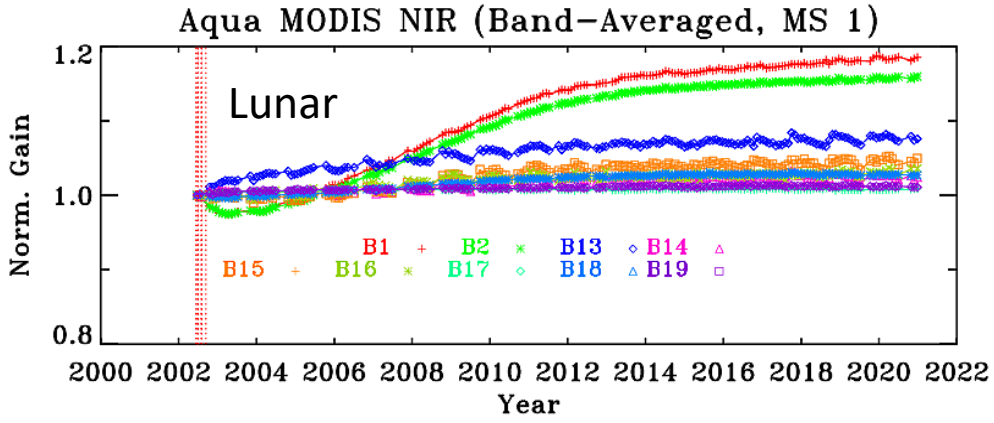
SD AOI = 50.25° Lunar (SV Port) AOI = 11.2°

Aqua MODIS
Gain Trending from SD and Lunar





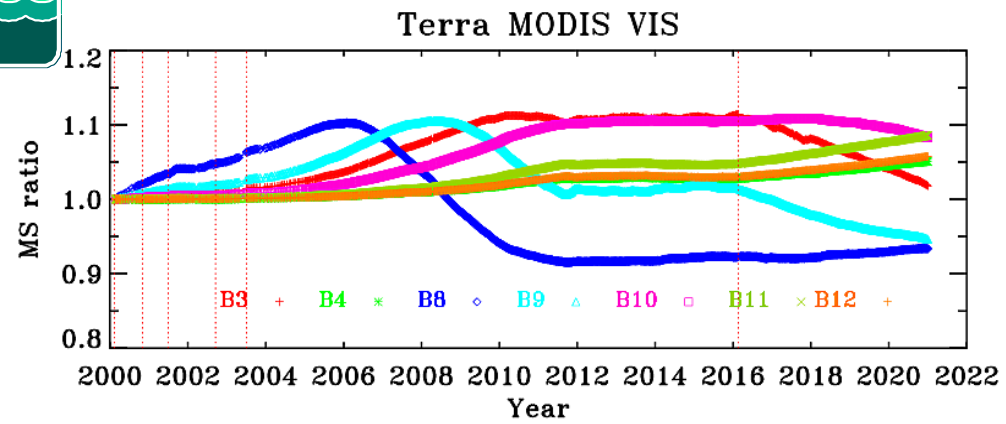


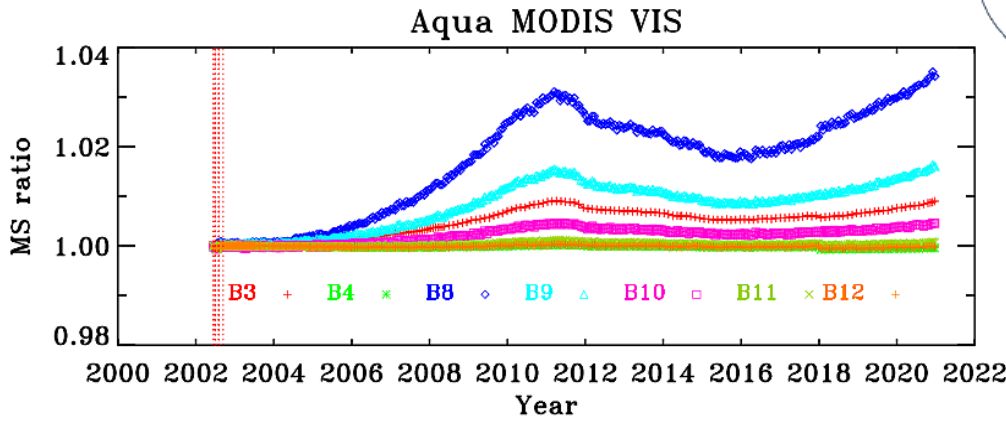


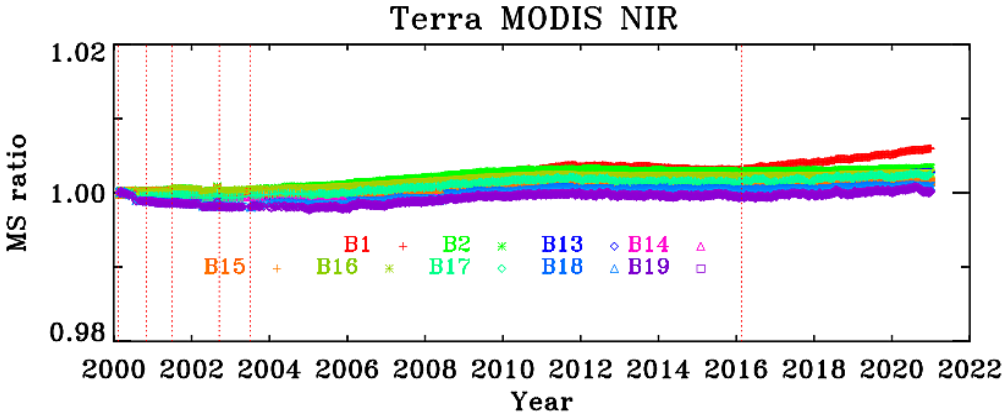
SD & Lunar measurements used to derive the on-orbit RVS change

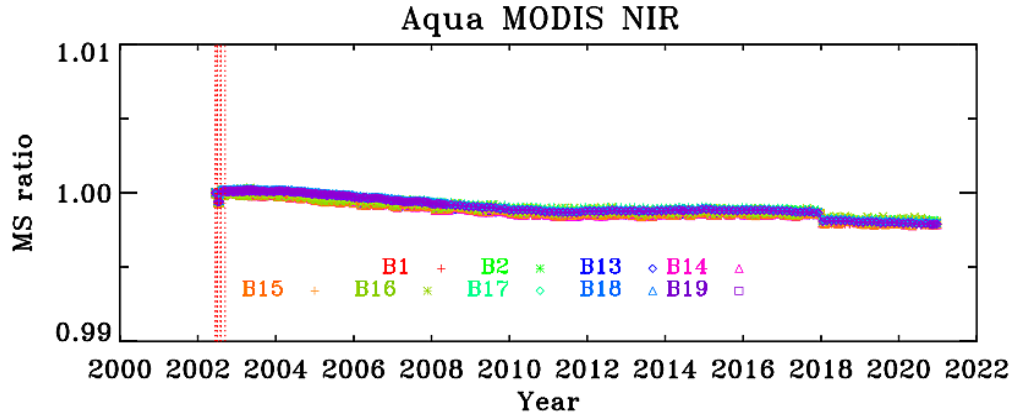
SD AOI = 50.25° Lunar (SV Port) AOI = 11.2°

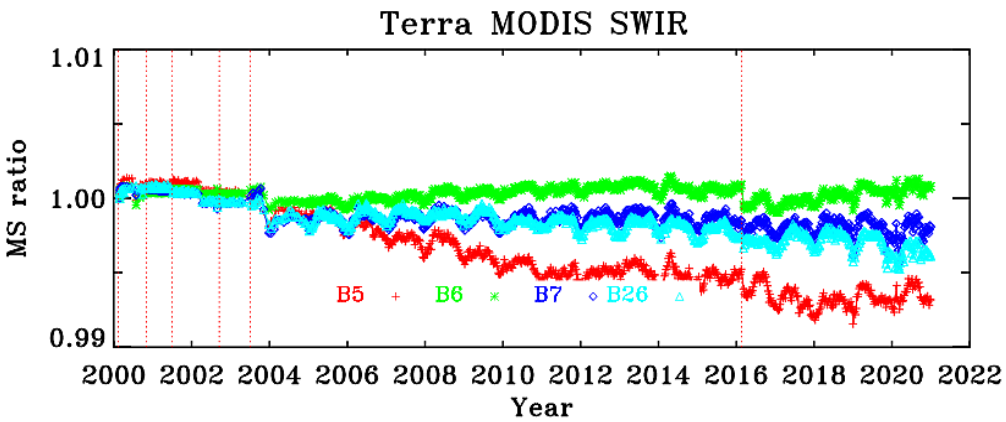
Gain Mirror Side Ratio Trends from SD

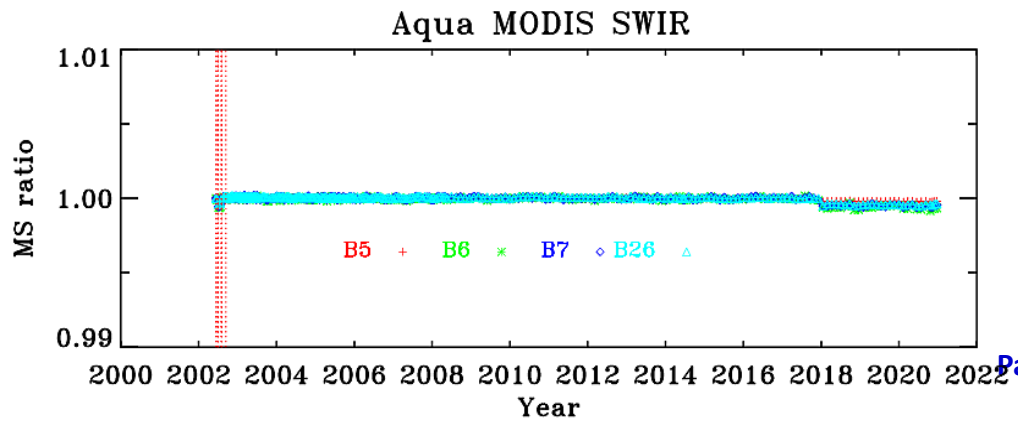




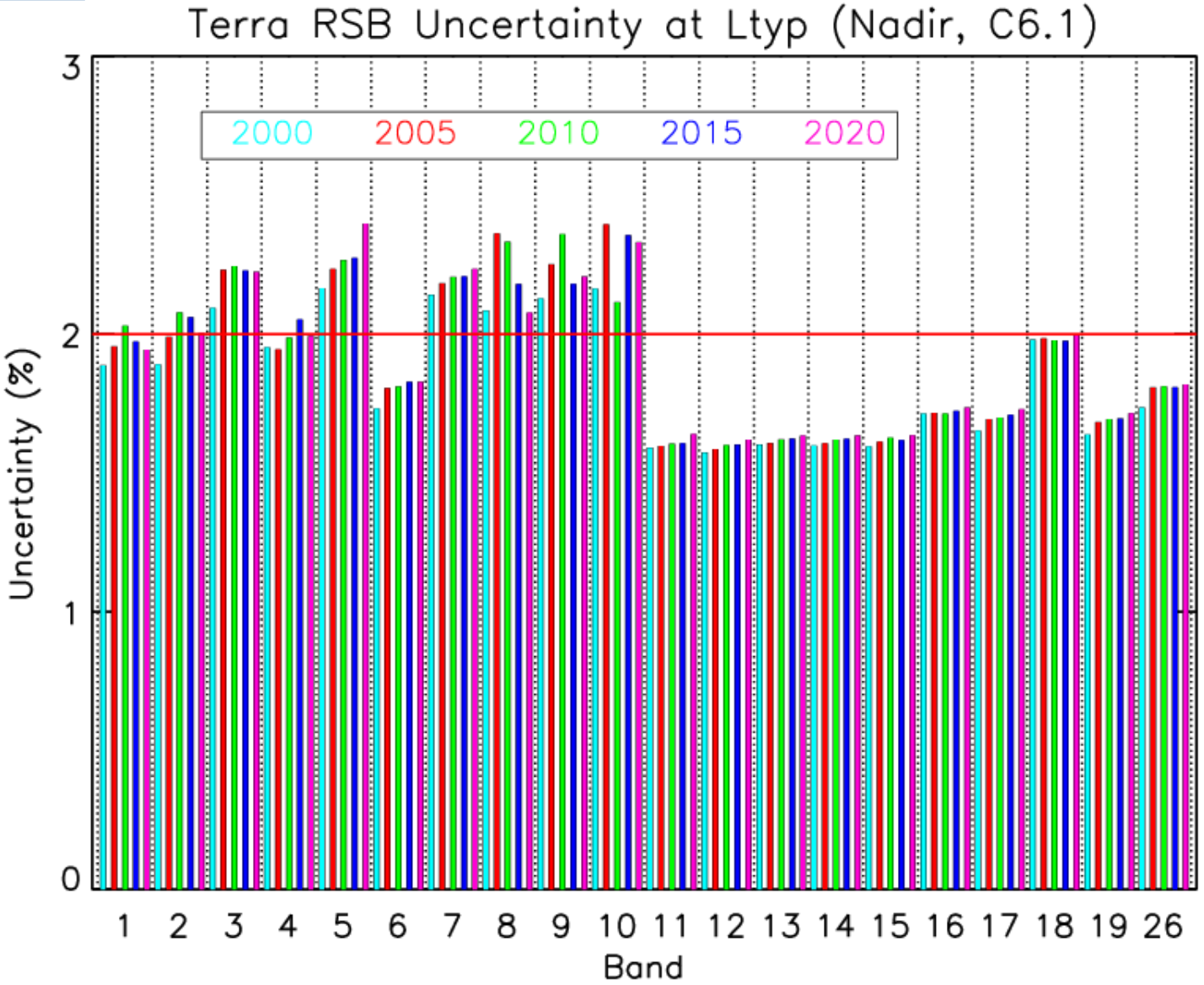








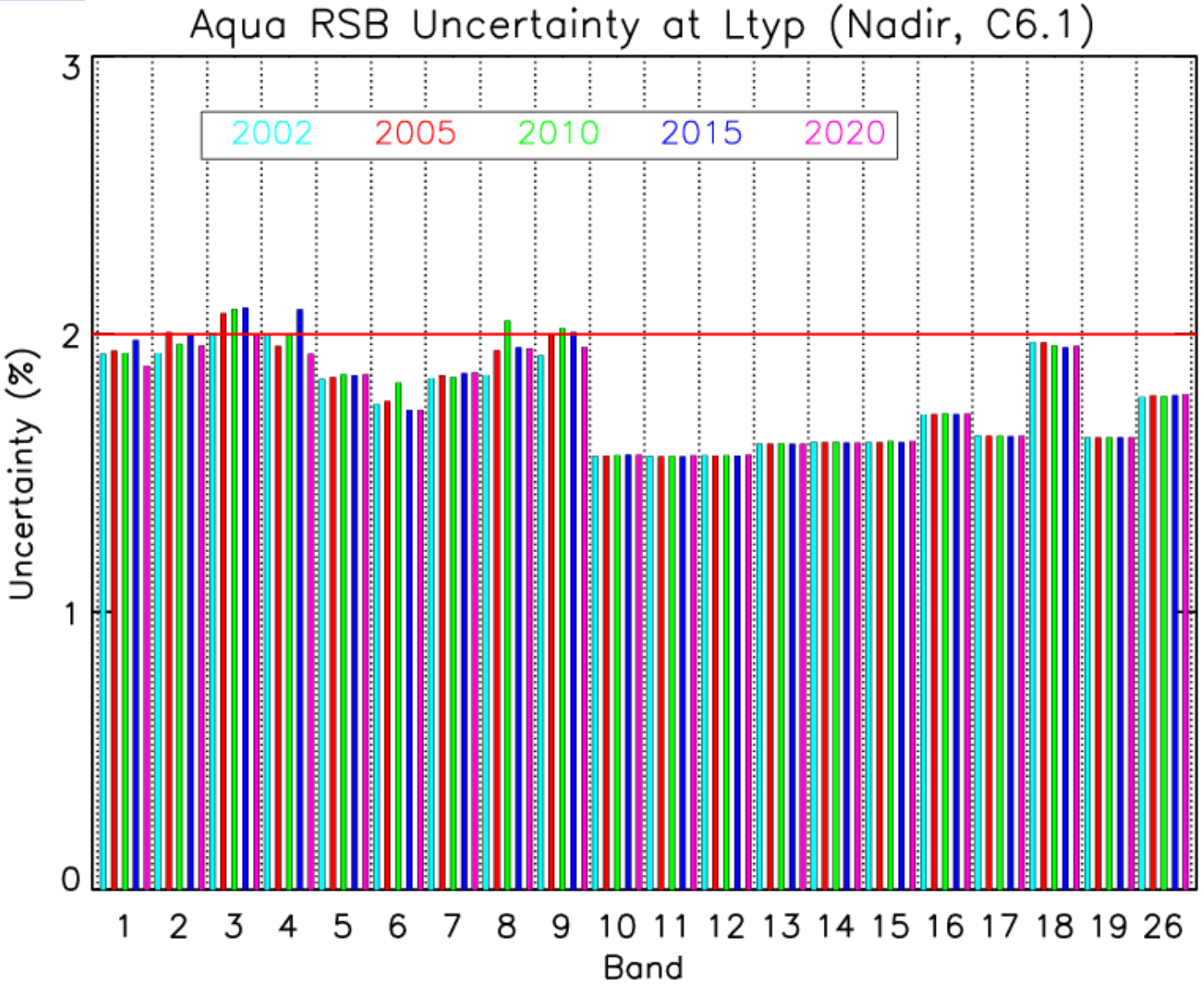
MODIS RSB Uncertainty Trends



Most bands continue to meet the specification.

- Additional uncertainty associated with the bands that employ EV-based RVS characterization approach (Terra bands 1-4, 8-10)
- On-orbit changes in the polarization sensitivity is also a contributing factor.

MODIS RSB Uncertainty Trends



Most bands continue to meet the specification.

- Additional uncertainty associated with the bands that employ EV-based RVS characterization approach (Aqua bands 1-4, 8,9)

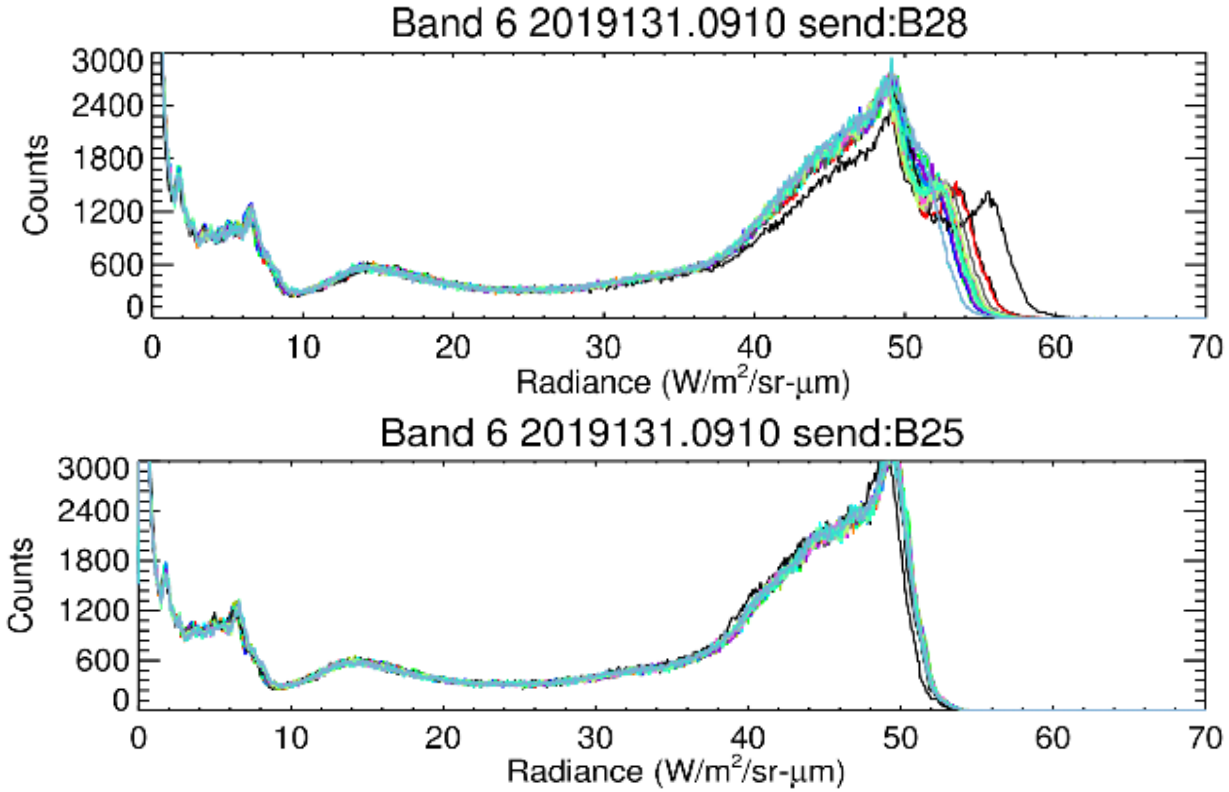
Terra SWIR crosstalk sending band switch

Collection 6.1

- SWIR bands (5-7 and 26) have electronic crosstalk and out-of-band (OOB) optical leak problems, known since before launch.
- In previous Collections through C6.1, band 28 was used as the sending band for crosstalk correction. Due to continued performance degradation of band 28 (PV LWIR crosstalk), a switch was made to use band 25 as sending band in forward production starting June 2019.

Collection 7

- Band 25 will be used as sending band over entire mission.
- More stable gain and reflectance trending, especially in later years of mission
- Significantly reduced detector striping
- Significantly reduced subframe striping



X. Xiong, A. Angal, Y. Li, and K. Twedt, J. Appl. Remote Sens. **14(4)**, 047503 (2020)